Northern Sandplain Kwongan: community biomass and selected species response to fire

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Abstract

The mixed, taxonomically diverse shrublands of the Northern Sandplains near Badgingarra, Western Australia recover rapidly following fire and by seven years, above ground biomass has reached a maximum of about 16-18 t ha^{-1}. Such rapid build up of biomass is typical of fire-prone communities of kwongan dominated by long-lived autoregenerating species. Sampling from a series of deep sand sites of known fire history provided material for case studies of biomass recovery and development of polycarpic fire ephemeral (*Tersonia brevipes* Moq. in DC.), four obligatory reseeding species (*Leucopogon conostephioides* DC., *Petrophile media* R. Br., *Beaufortia elegans* Schauer. and *Hakea obliqua* R. Br.), a species normally exhibiting both seed- and resprouting-regeneration (*Jacksonia floribunda* Endl.), and two long-lived resprouting species never recorded at the sites as currently regenerating from seed (*Hibbertia hypericoides* (DC.) Benth. and *Hypocalymma xanthopetalum* F. Muell.). Very great differences were observed between representatives of each fire response category in growth rates and shapes of developing shoot canopies of the species. Community biomass was directly correlated with foliage projective cover allowing an easily obtained value to estimate fire fuels. The implications of the data are considered in relation to the prediction of fuel loads and design of controlled burning regimes for the region.

Introduction

Upland regions in the Irwin District of the kwongan of the South-West Botanical province (Beard 1980) are dominated by shrublands of highly uniform visual appearance but of great floristic richness and diversity (Lamont *et al.* 1984, Bell and Loneragan 1985). The mediterranean weather pattern of the region, by providing cool wet winters and long dry summers, promotes a rapid accumulation of above ground biomass between successive fires. These conditions, compounded with the tendency for certain plant species to be highly flammable in living or dead state (Pompe and Vines 1966), present serious summer fire control problems for land managers in the region, especially where fire-prone natural plant communities are intermixed with farmland committed to arable crops or pasture.

Fire management in the Northern Sandplains is aimed at fulfilling two major criteria. First and foremost farmers and pasturalists must be protected from wildfires emanating from adjacent native vegetation. Secondly, sufficient areas of native plant communities must be maintained for conservation purposes, while still serving the needs of a commercial apiculture industry, the wildflower seed and cut-flower trades, and tourism (Bell *et al.* 1984). These areas of native vegetation must in turn be protected from fires originating from roadsides or burning operations in adjacent farmland.

Techniques for estimating fuel loads in the shrublands of the Northern Sandplain have recently been developed (Schneider and Bell 1985), and certain general characteristics of the response to fire by vegetation in the region have been considered in relation to apiculture (van der Moezel *et al.* 1987). The vegetation generally increases to a near maximum value of 70% foliage projective cover within 7-10 years (Bell *et al.* 1984), rates of recovery being more rapid in plant communities of the lateritic peneplain surfaces than on adjacent quartzitic sands. The floristic composition of these two edaphically-distinct substrata is also quite different, so differing recovery profiles might relate as much to the species present as to contrasting soil types (Bell and Loneragan 1985).

The first objective of this study was to document community foliage canopy cover and biomass changes occurring after fire in the vegetation of a series of deep sand sites, using a combination of projective cover density measurements and direct assessments of dead and living plant material harvested from randomly selected quadrats within a series of sites of known fire history. A second objective was to examine in detail patterns of biomass recovery in a number of common species typifying the major classes of fire response (see Bell *et al.* 1984) shown by flora of the study area. The data obtained are discussed in relation to the development of rational and effective fire management policies for the region.

Methods

The study area was centred around Badgingarra (30°23'S, 115°30'E), approximately 200 km north of Perth, Western Australia. Individual sites extended from the Badgingarra National Park (30°20'S, 115°25'E) northwards to the region of Jurien Road (30°14'S, 115°16'E). They were selected on the basis of records of the Western Australian Bush Fires Board to represent stands burned 5 and 9 months, and 2, 3, 4, 5, 6, 7, 8, 11, 12 and 17 years prior to sampling in March 1982. The study sites lay over deep quartzite, nutrient-poor sands, analytical data for which have been recently published (Pate *et al.* 1985).

Records of community above-ground biomass were determined by collecting all living and dead plant material from ten randomly selected 1 m^2 quadrat samples at each site. The samples from each quadrat were weighed individually in the field using spring balances, and weighed subsamples of bulked material from each site taken back to the laboratory for oven drying (65°C), to enable field biomass fresh weight data to be converted to dry matter. Each quadrat was assayed for foliage projection cover before its biomass was collected, so that relationships between biomass and cover and between biomass and age since last fire could be determined by linear regression analysis.

A detailed analysis of develoing canopy structure was made for 8 common shrubby species (Table 1) which collectively included all major categories of response to fire represented in the community. Twenty individuals of a species were collected from all sites at which that species was present. The above ground parts of each individual plant were air dried in intact state and then partitioned horizontally into a series of 10 cm segments (except for the large species *Hakea obliqua* with 20 cm increments). Each stratum of the shoot was then measured for foliage diameter and dry weight. Combining data for each sample of 20 plants, shrub structure profiles were then constructed depicting mean canopy shape and weight distribution for each species for the range of ages since last burn (Gibberto *et al.* 1977).

Results and discussion

Increase in community biomass following fire

Canopy cover and above-ground biomass in the study area increase rapidly in the first 7 years following fire, thereafter tending to remain at levels of approximately 16-18 t ha^{-1} (Fig. 1). This period of rapid increase in biomass correlates with the main flush of regeneration of woody shrubs establishing from fire-resistant underground root stocks. A study of 152 species from sandy habitats in the Badgingarra-Jurien region has indicated that 66% resprouted in such manner following fire, and that at least a similar proportion of biomass of a site was likely to consist of these resprouter species (Bell *et al.* 1984). Other studies on sandy sites from the region, and of the floras of neighbouring lateritic sites have shown even higher proportions of resprouting species (Bell and Loneragan 1985, van der Moezel *et al.* 1987).

The plateau of biomass at approximately 16-18 t ha^{-1} places the Northern Sandplain kwongan at the low end of values for above-ground biomass recorded for mediterranean-climate shrubland ecosystems in California, France and the eastern Australian states (see Gray and Schlesinger 1981, Bell *et al.* 1984). Biomass achievements of Northern Sandplain shrublands are,

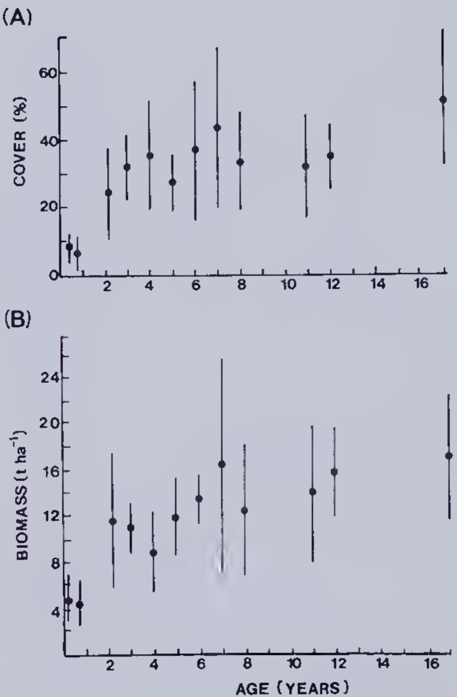

Figure 1.—Foliage projective cover percentage (A) and total above ground biomass (litter plus above-ground plant material) (B) of deep sand shrubland sites in the Northern Sandplain region between Badgingarra and Jurien, Western Australia.

however, more than double those reported for the open matorral of Chile (Mooney *et al.* 1977), and lie within the range of 11-26 t ha^{-1} reported for mature shrub-dominated communities in southwest Cape Province, South Africa (Kruger 1977). Elsewhere in the kwongan of Western Australia, biomass values for closed shrub communities on calcareous sands at Two Peoples Bay near Albany were reported to have reached near-maximum biomass at 16 t ha^{-1} after 9 years regrowth (Bell *et al.* 1984); a site on deep sands south of Eneabba carried 7 t ha^{-1} after 9 years (Hopkins and Hnatiuk 1981), and a mature shrub-dominated stand of unknown age on depauperate grey sands at Tutanning Nature Reserve showed 13 t ha^{-1} (Brown and Hopkins 1983). As mentioned above, relatively early achievement of a plateau in biomass with age in kwongan is probably related primarily to the large (Fig. 1B) proportional contribution of sprouters to the ecosystem, but it might equally reflect a limited overall carrying capacity in the dry, nutrient-poor sites typical of this class of vegetation.

Cover to biomass relationships

Analyses of data from all study sites showed that foliage projective cover percentages were directly related to biomass according to the following regression equation (biomass (t ha^{-1}) = 2.99 + 0.25 cover (%), df = 115, $r = 0.85$, $p < 0.01$). An essentially similar pattern of biomass recovery following fire is reported for South African fynbos communities (Kruger 1977), although the perennial herbaceous component of these communities is greater than kwongan.

Other published data on cover density have provided estimates of vegetation recovery following fire in a number of mediterranean-climate vegetation types. For coastal heaths at Dark Island, South Australia, cover percentages increase steadily to a maximum of approximately 70% after 10 years since burning, and remain fairly constant for the next 15 years (Specht *et al.* 1958). Cover values following fires in the chaparral of southern California, however, show two peak periods, the first after 2-5 years coincide with dominance by annuals, herbaceous perennials and short-lived subshrubs, the second peak, after 8-17 years, with the resurgence of larger woody shrubs typical of the climax mature vegetation of the region (Horton and Knaebel 1955, Keeley and Keeley 1981). According to Specht *et al.* (1985) cover values for fire-prone vegetation possessing a herbaceous phase in its pyric succession are generally not well correlated with biomass, due to the much greater weight to cover ratio of later stage samples (Specht *et al.* 1985).

The rapid regrowth of the Northern Sandplain shrublands means that stands achieve a capacity to support a fire very soon after the previous fire. Indeed, instances of fires burning through regions carrying only a three-year-old fuel load have been reported for the Beekeepers Reserve north of Jurien, albeit only under conditions of exceptionally intense late summer temperatures (>40°C) involving low humidities (<15%), high winds (>40 km hr^{-1}) and dry fuel conditions (Burking and Kessell 1984). It is apparent, however, that on average, stands of age 2-6 years will have considerable less biomass than older counterparts and would be accordingly less prone to wildfires. Prescribed burning on a rotation of five to seven years, or even less, would therefore appear to be an eminently sensible means of reducing fuel loads to less dangerous proportions. However, this advantage must be weighed against potential problems in conservation of individual species, especially rare or restricted fire sensitive species which normally take a number of years after germination before commencing to flower and set seed (see Hopper and Muir 1984). This will constitute a particularly serious problem where the species in question retain their seed load in the plant canopy rather than in the soil (Table 1).

Table 1

Characterisitics of species selected for detailed study on recovery after fire.

Species	Family	Regeneration Mode	Seed Store
Leucopogon conostephioides...	Epacridaceae	Obligate seed regenerator	Soil
Hakea obliqua	Proteaceae	Obligate seed regenerator	Plant
Beaufortia elegans..................	Myrtaceae	Obligate seed regenerator	Plant
Tersonia brevipes....................	Phytolaceae	Obligate seed regenerator	Soil
Petrophile media......................	Proteaceae	Obligate seed regenerator	Plant
Hibbertia hypericoides	Dilleniaceae	Resprouter	Soil
Jacksonia floribunda..............	Papilionaceae	Both a resprouter and reseeder	Soil
Hypocalymma xanthopetalum....................	Myrtaceae	Resprouter	Soil

Growth and developing canopy characteristics of selected species

(a) Polycarpic fire ephemerals

Monocarpic and polycarpic fire ephemerals are relatively sparse in the Northern Sandplain in terms of number of species and relative biomass (Pate *et al.* 1985) in comparison with the highly prolific post-fire herb flora of Californian chaparral (Muller *et al.* 1968, Keeley and Keeley 1981). The species *Tersonia brevipes* is a typical short-lived polycarpic perennial of kwongan in showing fire-obligate germination, extremely fast early growth rates, early maturity, high reproductive effort in proportion to vegetative biomass, and a relatively short life span (see Pate *et al.* 1985). Fast early growth of these successional species is generally held to promote an immediate conservation of nutrients following disturbance such as fire, and thus minimize leaching losses of nutrients in such circumstances (Marks and Bormann 1972, Likens *et al.* 1978, Foster *et al.* 1980, Nilsen and Schlesinger 1981).

Initial growth in *Tersonia brevipes* (Fig. 2a) was predominantly in a vertical direction though formation of a short lived leafy shoot, but a semi-woody creeping habit is then quickly attained through subsequent development of a number of basal axillary shoots. By four years the radiating stems of plants of the species may encompass an area up to 240 cm in diameter with all biomass restricted essentially to within 10 cm of ground level. By 4 years mean plant weight had reached 220 g, but by 5 years virtually all plants had senesced and died within the area (see also Pate *et al.* 1985).

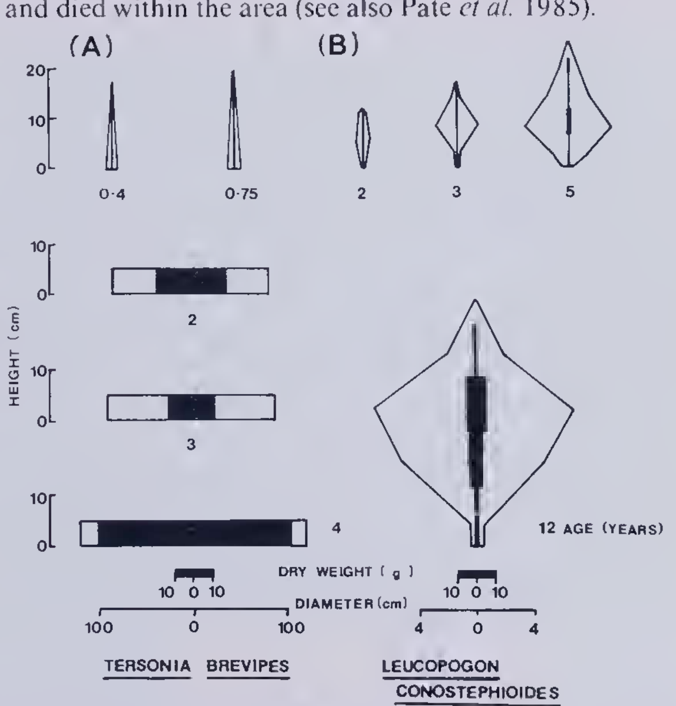

Figure 2.—Mean shrub dimensions of the short-lived fire ephemeral, *Tersonia brevipes*, following fire in the Northern Sandplain shrublands (A). Histogram of dry weight for 10 cm increments of radial distribution from the root system.

Mean shrub dimensions of obligatory reseeding species, *Leucopogon conostephioides*, following fire (B). Data includes height, 10 cm increment diameter and dry weight distribution and total dry weight.

(b) Obligatory re-seeding species

Patterns of regrowth following fire were essentially the same in the two seeder species *Leucopogon conostephioides* (Fig. 2b), and *Beaufortia elegans* (Fig. 3a). Over the first two years each species grew mostly in a vertical fashion, but thereafter increasingly in diameter as well as in height. In *Leucopogon conostephioides*, mean plant above ground dry weight increased from 0.20 g $plant^{-1}$ at two years to 0.36 g after 3 years, 2.7 g after 5 years and 9.6 g $plant^{-1}$ after nine years growth (Fig. 2b). Mean heights of the 2-, 3-, 5- and 12-year plants were 11, 17, 23 and 44 cm, respectively. As plants aged, biomass tended to be distributed disproportionately toward the upper part of the stem, giving a decidedly "top heavy" plant.

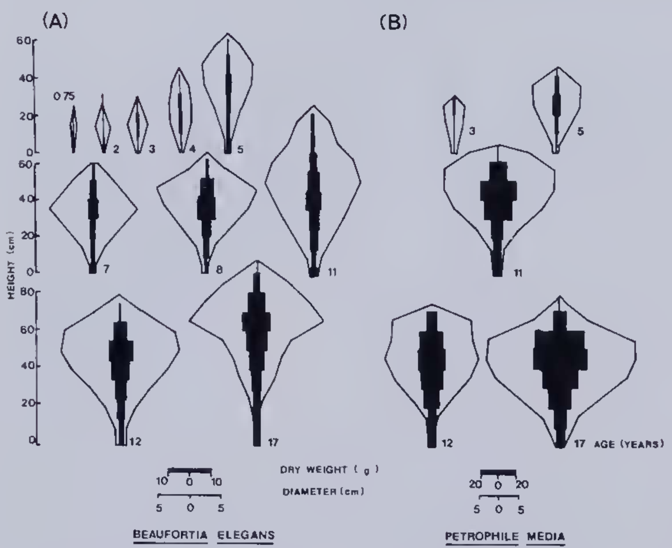

Figure 3.—Mean shrub dimensions of obligatory reseeding species, *Beaufortia elegans* (A), and *Petrophile media* (B) following fire in the Northern Sandplain shrublands.

Beaufortia elegans seedlings were generally larger than those of comparably-aged *Leucopogon conostephioides*. Plants of *B. elegans* growing in a 17-year old stand were nearly 100 cm tall and weighed more than 75 g (Fig. 3a). In these old plants the stratum between 60 and 70 cm above soil level contained the greatest amount of biomass.

Petrophile media. another obligatory reseeding species, was unfortunately encountered only at sites within the age range 3-17 years. When mature, this species showed similar "top heavy" biomass distribution profiles to those of *Beaufortia elegans*. although above ground parts of *P. media* plants were generally more than twice as large and heavy as *B. elegans* (Fig. 3b).

The largest obligatory reseeding species encountered in the deep sand communities of the study region was *Hakea obliqua* (Fig. 4). In areas estimated to be 17 years old since the last fire, plants had a mean height of 2.7 m and a mean above ground dry weight of 1.44 kg. The distribution of this biomass with height was more uniform in this species compared with the previous three examples, as readily apparent from the generally spindly profile of the species in the field.

Table 2

Linear regression equations and statistics for the relationship of mean plant height and age for four obligatory reseeding species of the Northern Sandplain shrublands.

Regression Equation	d.f	v	p
Age (yr) = —1.32 + 0.41 *Leucopogon conostephioides* height (cm)	50.99	<	0.01
Age (yr) = —2.89 + 0.21 *Beaufortia elegans* height (cm)	80.94	<	0.01
Age (yr) = —4.28 + 0.29 *Petrophile media* height (cm)	40.96	<	0.01
Age (yr) = —2.90 + 0.07 *Hakea obliqua* height (cm)	90.99	<	0.01

Highly significant linear regressions between height and age were found for each of these four obligatory seed-regenerating species (Table 2). This relationship has already been suggested as a useful means for predicting age of sites for when fire records are not available (Bell 1985). We would now further suggest that, using such regression equations, and data on mean heights of a range of seeder species, one would have a simple method for estimating stand age at a site for which fire records were not available. Following this, using the age-biomass data of Fig. 1., predictions could be made of fuel loads in the region, and thus determine whether or not a prescribed burn were both feasible and desirable.

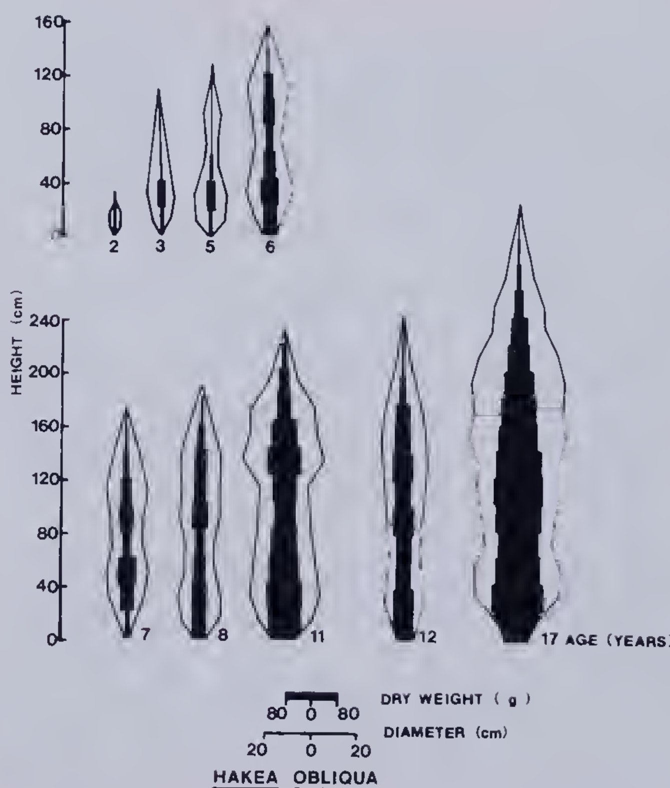

Figure 4.—Mean shrub dimensions of the obligatory reseeding species *Hakea obliqua* following fire in the Northern Sandplain shrublands.

(c) Resprouting species also regenerating freely from seed

Species which possess the ability both to resprout, and to establish abundant seedlings following fire may be considered to have distinct advantages over species exhibiting only one or other of these regeneration strategies. For instance, Keeley (1977) noted that the most abundant chaparral species in California, *Adenostoma fasciculatum*, reproduces following fire both by resprouting and from germinating seed, as do a number of successful species of the Californian coastal sage vegetation (Malanson and O'Leary 1982).

In the Northern Sandplain of Western Australia, *Jacksonia floribunda*, constitutes a common species possessing the above mentioned abilities (Bell *et al.* 1984). By being able to distinguish between unscarred seedlings established following the last fire and fire-scarred resprouting individuals which had clearly survived at least one fire at the site, it was possible to compare growth patterns and morphologies of virgin seedlings and previously established survivors. Seedlings of *Jacksonia floribunda* were then found to produce above-ground biomass at very slow rates, yielding after eight years, heights of approximately 40 cm and above ground dry weights of only 2.7 g dry weight (Fig. 5a). By comparison resprouting individuals in the some 8-year study site averaged nearly 80 cm in height and carried above-ground biomass averaging of 79 g dry weight (Fig. 5b).

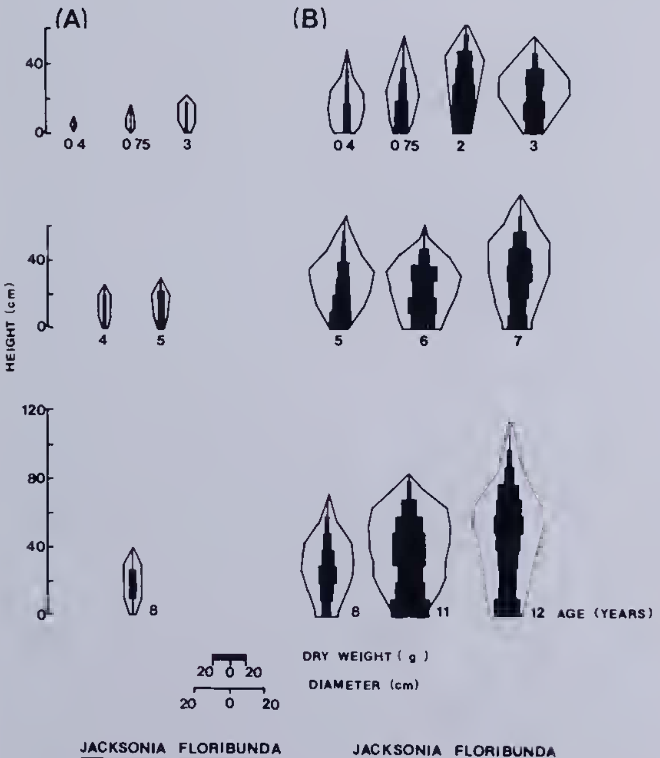

Figure 5.—Mean shrub dimensions of *Jacksonia floribunda* seedlings (A) resprouting individuals (B) following fire.

There are inherent difficulties in interpretation of data on biomass of surviving plants of a resprouter species across a sequence of sites because the mean age of survivors of one population may be very different from that of another site. This is especially so if earlier fires or other environmental events have given very different patterns of recruitment at the sites in question. The present data accumulated for *Jacksonia floribunda* typify this problem; e.g. the population of plants in the region burned two years prior to sampling had a mean total dry weight of 126 g plant^{-1} compared with only 79 g^{-1} in a neighbouring site known to have had an 8 year interval since the last burn (Fig. 5b).

(d) Long-lived resprouting species, regenerating extremely rarely from seed

Rapid regeneration of resprouter species was also demonstrated for two common non-clonal, resprouting species, *Hibbertia hypericoides* (Fig. 6a) and *Hypocalymma xanthopetalum* (Fig. 6b). These two species are exceptionally common members of the deep sand communities of the Northern Sandplain (Bell and Loneragan 1985), but, in the authors experience, have never been observed to be regenerating successfully from seed (Bell *et al.* 1984). As with other long lived sprouters, each exhibits highly heterogenous population structures in terms of number, mass and length of regenerating shoots per plant, tap root diameter, and inflorescence number and fruit reproduction. Unfortunately, the real age of resprouting individuals cannot be assessed with certainty, as growth rings in tap roots are not readily apparent, especially where root stocks have become split or partly destroyed by termites. In any event there is no proof that any growth rings which are present have been produced on a strictly annual basis.

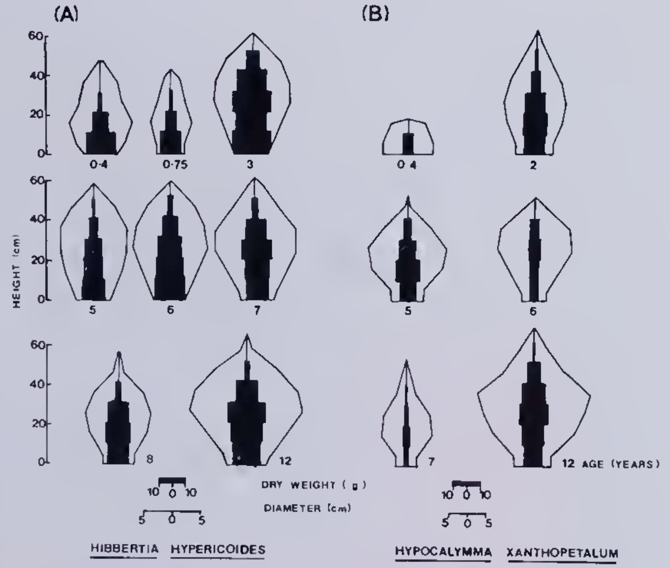

Figure 6.—Mean shrub dimensions of the long-lived autoregenerating species, *Hibbertia hypericoides* (A) and *Hypocalymma xanthopetalum* (B) following fire.

These two long-lived resprouting species showed essentially similar habit to resprouting *Jacksonia floribunda*, and, regardless of size and age, mean diameters of their above ground stems were consistently greater than that of the earlier-mentioned seed regenerating species. In contrast to seeders, resprouters gained dry matter most rapidly over the first three years after a fire (Fig. 6), and with age, showed no tendency for the biomass of their shoots to become concentrated especially towards the top of their shoots.

GENERAL CONCLUSIONS

Species of the Northern Sandplain that regenerate by resprouting appear to have inherent advantages over obligate seeder species in possessing a deeply penetrating massive root stock, from which nutrients can be mobilized to give quick recovery of above ground biomass after fire. The multiple shoots generated from these root stocks give the regenerating shrub a highly characteristic shape, with wide basal diameter and biomass initially concentrated mainly at the base of the plant. Regrowth of resprouters is very rapid in the first 2-3 years after fire followed by a slow and gradual increase over at least the next 14 years.

The seed regenerators studied in the Northern Sandplain shrublands have the same general habit as reported for other fire-sensitive Western Australian species (Baird 1977). Typically a single main stem is established and persists, the root system is typically shallow and of fibrous character (Dodd *et al.* 1984), and biomass is eventually located mostly in the upper reaches of the plant. As shown by the silhouettes of shoot shape and mass distribution described in this paper, those of seeders contrast markedly with those of root-grown resprouters. Moreover, since the seeders tend to establish in spaces between the regenerating crowns of the resprouters, and with time may even overtop the sprouters, both are able to coexist successfully for many years of a post fire interval. Indeed, a properly balanced mix of seeders and sprouters, with essentially complementary shoot canopies and rooting morphologies, is likely to maximize utilization of existing ground cover and resources of water and nutrients. Within this framework also, fast growing ephemerals such as *Tersonia brevipes* occupy a critical role early in a pyric succession by progressively recovering nutrients released from fire into plant biomass (see Pate *et al.* 1985).

Were it possible to extend information on canopy shape and weight distribution to all major species of some chosen aged community, and to combine this with measurements of density of these species, it would be possible to construct computer-simulated graphical representations of typical biomass structure, and thus assist in predicting how fuel loads are distributed over time and space. Such information would be particularly valuable to a better understanding of fire management of the community.

This study has looked in detail at the responses to fire of only a small sample of species from a highly diverse flora. For the meantime, faced with a paucity of data on regeneration strategies, ecologists must follow a conservative path when using fire as a management tool in these regions (Bell *et al.* 1984, Hopper and Muir 1984). On the one hand, there is the danger that too-frequent fires might result in the loss of those obligatory seed-regenerating species which take an unusually long time to achieve first reproduction (van der Moezel *et al.* 1987). Important apicultural species might well fall within such a category. On the other hand, long periods of fire prevention in kwongan generally lead to the build up of dangerous levels of fuel, and thus increase the possiblility of large scale wild-fires sweeping through shrubland and intervening pastureland. Until the Norther Sandplan escosystem is much better understood, fire management policies should consist of planned mosaics of strategically reduced fuel zones, enclosing less frequently burnt regions, in which already indentified, endangered seeder species might be able to survive. Designation of such a policy within National Parks, bee pastures, and specific recreation areas would further ensure sensible planned long-term maintenance of the species and their unique parent communities in the interests of all parties concerned.

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